FAR-INFRARED MAPPING OF DUSTY ELLIPTICAL GALAXIES

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ABSTRACT Preliminary results from a program to map the thermal far-infrared emission from cool dust in elliptical galaxies using the Yerkes 60-Channel Camera on the Kuiper Airborne Observatory (KAO) are presented. The 160 μm emission from the elliptical NGC 6524 is apparently extended over the optical galaxy whereas the 100 μm emission is unresolved. This implies a dust temperature gradient consistent with that expected for dust with Galactic properties exposed to the general interstellar radiation field of the elliptical galaxy. Observations of the elliptical NGC 5666 and the NGC 7463/4/5 compact group (consisting of the elliptical NGC 7464, the S0 NGC 7465, and the spiral NGC 7463) are also discussed.

INTRODUCTION

Early-type galaxies generally are dominated by an old stellar population and contain little gas and dust compared to the typical late-type spiral. However, since the launch of the IRAS satellite in the mid-1980's, it has been known that many of these systems contain small quantities of cold interstellar matter: 45% of all elliptical galaxies show thermal dust emission at $60-100\mu$m (Knapp *et al.* 1989) with temperatures apparently similar to dust in spiral galaxies. Ratios of global gas quantities (such as CO and HI 21 cm emission) to the far-infrared emission are also indistinguishable from those for spirals (Lees *et al.* 1991).

However, before last year, only one dusty elliptical galaxy (NGC 5128; Cen A) was close enough to be fully mapped by IRAS (Eckart *et al.* 1990) and at higher resolution with the KAO (Joy *et al.* 1988; see also Lester 1993, these proceedings). Only two dusty ellipticals, both strong radio sources (Cen A and Per A), had been observed at all at wavelengths between 100 μm and 2 mm.

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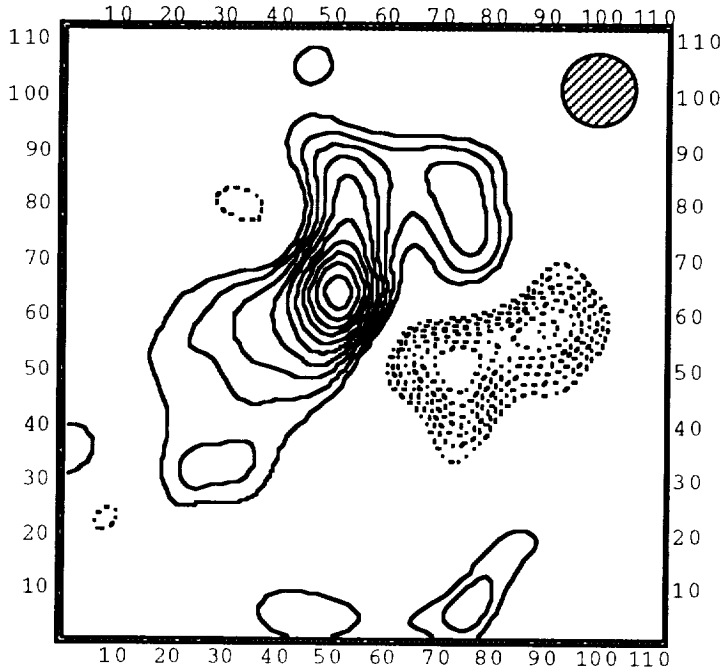

FIGURE 1 The 160 μm KAO map of NGC 6524. The positive contours show the ON beam (see text) at 1.5σ, 2.1σ, 2.7σ, 3.3σ, etc. The negative (dashed) contours show the OFF beams. Each pixel in the image is 3″.5 and the resolution, shown in the upper right, is 44″.

OBSERVATIONS

In 1992 we began a program to study the infrared properties of IRAS-bright elliptical galaxies. In April and July 1992 we mapped three ellipticals in the far-infrared using the Yerkes 60-channel camera on the Kuiper Airborne Observatory. The camera is an 8×8 bolometer array (without the corner pixels) operating at the diffraction limit of the KAO telescope with pixel sizes of 16″, 25″, 44″, and 44″ at wavelengths of 60, 100, 160, and 200 μm respectively (results from an earlier version of the camera with 32 pixels are presented in Engargiola 1991).

We are also involved in projects to obtain JHK images of dusty ellipticals using the GRIM near-infrared camera on the ARC telescope at Apache Point, New Mexico and to define the 350-1100 μm submillimeter spectra of these galaxies using the James Clark Maxwell Telescope in Hawaii. Our ultimate goal is to use the stellar radiation field derived from the near-infrared images and the far-infrared and submillimeter photometry of the thermal dust emission to accurately model the equilibrium dust emission from elliptical galaxies.

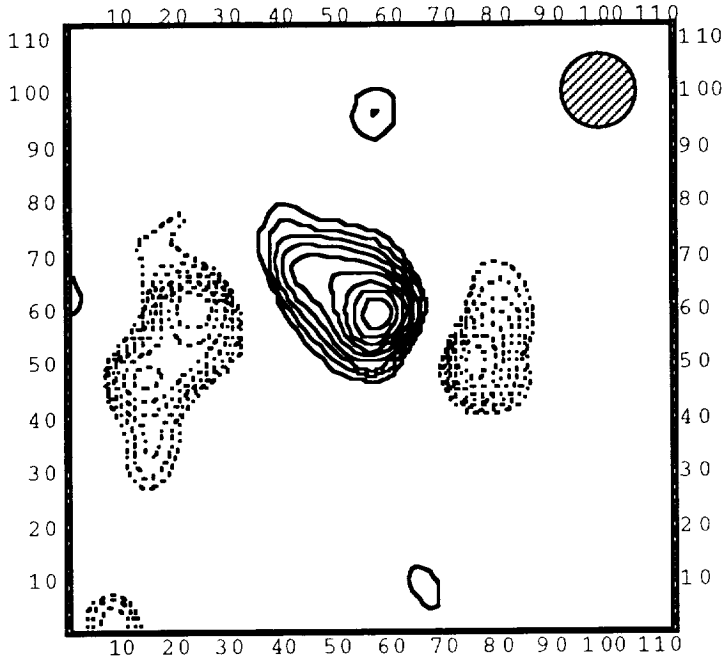

FIGURE 2 The 100 μm KAO map of NGC 6524. The positive contours show the ON beam (see text) at 2σ, 2.5σ, 3.1σ, 3.6σ, etc. The negative (dashed) contours show the OFF beams. Each pixel in the image is 2″ and the resolution, shown in the upper right, is 25″.

RESULTS

In Figures 1–3 we show the far-infrared maps of NGC 6524 (at 160 and 100 μm) and of NGC 5666 (at 160 μm) obtained from the KAO. At 160 μm our resolution is 44″ and the area plotted in Figures 1 and 3 is about 6′.4 on a side. At 100 μm the resolution is 25″ and the field of Figure 2 is about 3′.7 × 3′.7.

In order to maximize the integration time on these relatively faint objects we used a small chop throw of about 2′which meant the source was on the array on both ON and OFF beams. The result of doing the background subtraction (ON−OFF) produces two negative half-intensity images of the source on either side of the positive image. This can be seen clearly in Figures 1–3.

NGC 6524 is classified as E/S0 in the UGC catalog. It is quite isolated, with the nearest neighbor being almost a degree away, and has a weak active nucleus with broad emission lines (Merighi *et al.* 1991). It has the distinction of being the second-brightest elliptical at far-infrared wavelengths (after Cen A) with flux densities measured by IRAS of 7.9 Jy at 100 μm and 3.9 Jy at 60 μm (Knapp *et al.* 1989).

The most striking result from our KAO observations of NGC 6524 shown in Figures 1 and 2 is that the galaxy appears to be clearly resolved perpendicular

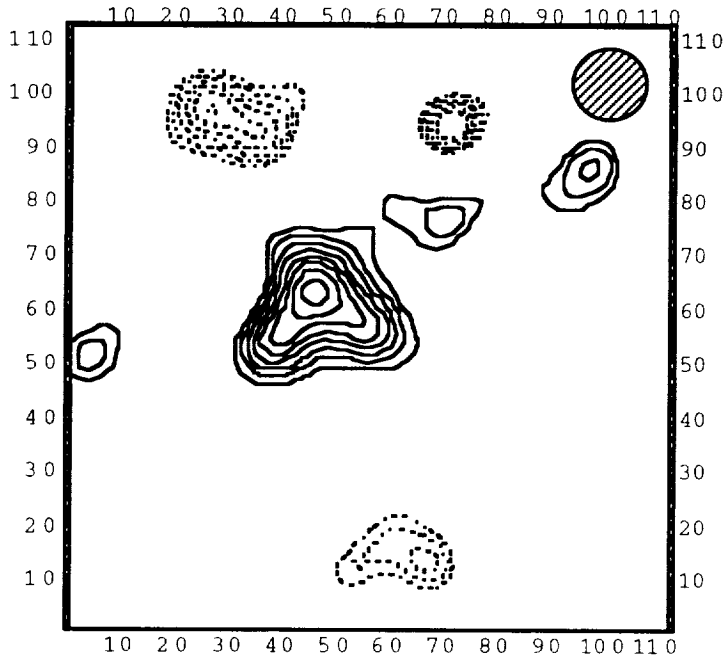

FIGURE 3 The 160 μm KAO map of NGC 5666. The positive contours show the ON beam (see text) at 2σ, 2.4σ, 2.8σ, 3.2σ, etc. The negative (dashed) contours show the OFF beams. Each pixel in the image is 3″.5 and the resolution, shown in the upper right, is 44″.

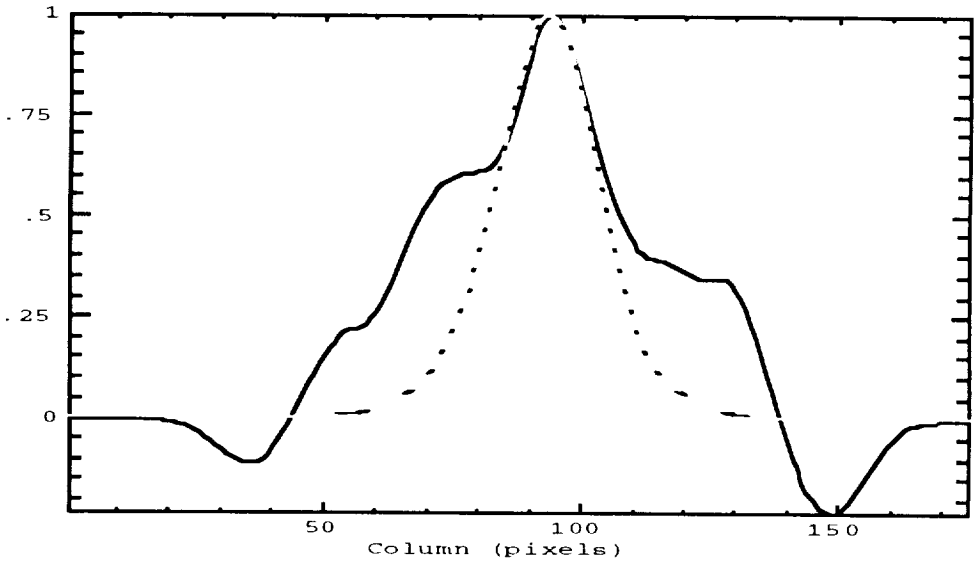

FIGURE 4 Cut through the NGC 6524 160 μm peak, perpendicular to the chop direction (solid line), and through a point source observed on the same night (dashed line). The abscissa is column number in pixels (each pixel is 3″.5 and the ordinate is far-infrared flux density relative to the peak. The resolution is 44″ or about 13 pixels.

to the chop direction at 160 μm (Fig. 1). A one-dimensional cut through the KAO 160 μm map is compared to that for a point source observed on the same night in Figure 4. The NGC 6524 profile resembles a point source superposed on lower-level extended emission. This extended emission is at about the 4σ level in our data, and we intend to reobserve this galaxy in 1993 to confirm this result. The 100 μm map in Figure 2, in contrast, shows no such extent, even though the resolution and map scale are almost twice as high. The FWHM of the 160 μm emission is about $2'$ (the optical size is $1'.7$), but at 100 μm the FWHM is less than $25''$.

The 160 and 100 μm KAO data imply a radial dust temperature gradient in NGC 6524. For a dust emissivity ($n = 2$) and grain parameters like those in our Galaxy, the central dust temperature is 29°K, in agreement with the observed IRAS 60 and 100 μm flux densities (Knapp *et al.* 1989) and our recent submillimeter photometry at the JCMT (Knapp, Lees & Rupen, in preparation). In the outer parts of the galaxy ($r \approx 1'$) the dust temperature must be less than 22°K. A simple model for optically thin dust in equilibrium in the old stellar radiation field defined by recent H and K band photometry by us at Apache Point predicts a dust temperature gradient of 29°K in the inner KAO beam to 20°K in the outer parts, in excellent agreement with our data. We hope to acquire additional observations of NGC 6524 this year on the KAO to actually measure the dust temperature in the outer parts of the galaxy.

Figure 3 shows our 160 μm KAO map of the isolated, gas-rich compact elliptical NGC 5666. NGC 5666 appears to be unresolved at this wavelength, which is not surprising considering the fact that its optical size is less than an arcminute. Its CO emission is also probably very compact (Lees *et al.* 1991) as is the central Hα and thermal radio emission (Wrobel & Heeschen 1988), but it has an extended, rotating HI disk over $3'$ (Lake, Schommer & van Gorkom 1987) which apparently does not emit strongly at 160 μm. Like NGC 6524, the IRAS 60-100 μm measurements, our 160 μm data point, and our recent JCMT submillimeter photometry indicate a central dust temperature of about 27°K.

The compact interacting system NGC 7463/4/5 was also mapped at 160 μm, but unfortunately the data were of poor quality due to telescope stability problems on the KAO last July. The S0 NGC 7465 and the spiral NGC 7463 were both apparently detected, with NGC 7463 having significantly cooler dust emission. This is also evident in the IRAS CPC images of this group (van Driel *et al.* 1993).

ACKNOWLEDGMENTS

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REFERENCES

Eckart, A., *et al.* 1990, *ApJ*, **363**, 451

Engargiola, G. 1991, *ApJS*, **76**, 875

Joy, M., Lester, D. F., Harvey, P. M., & Ellis, H. B. 1988, *ApJ*, **326**, 662

Knapp, G. R., Guhathakurta, P., Kim, D.-W., & Jura, M. 1989, *ApJS*, **70**, 329

Lake, G., Schommer, R.A., & van Gorkom, J.H. 1987, *ApJ*, **314**, 57

Lees, J.F., Knapp, G.R., Rupen, M.P., & Phillips, T.G. 1991, *ApJ*, **379**, 177

Merighi, R., Basso, L., Vigotti, M., Lahulla, J.F., & Lopez-Arroyo, M. 1991, *A&AS*, **89**, 225

Wrobel, J.M., & Heeschen, D.S. 1988, *ApJ*, **335**, 677

Van Driel, W., de Graauw, Th., de Jong, T., & Wesselius, P.R. 1993, *A&AS*, in press